

DYNAMIC RELATIONS WITHIN AND BETWEEN EARLY COMMUNICATION  
PROFICIENCIES AND KEY SKILL ELEMENTS' GROWTH TRAJECTORIES OF INFANTS  
AND TODDLERS

BY

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## Abstract

Preliteracy experiences inform language learning outcomes in early childhood—of which proficiency in expressive communication is requisite to children’s cognitive and social development. Identification of communication and language delays must be made as early as possible to inform appropriate intervention services targeting prevention of childhood disabilities. The Early Communication Indicator (ECI)—designed to monitor individual progress through brief repeated measurement of early expressive communication—is one of a growing class of general outcome measures emerging in early education and early childhood special education. Comparable to K-12 curriculum-based measures, the ECI is a resource for accountability as well as response to intervention (RTI) efforts. Current implementation applies differential scaling of four key skill elements into a total communication indicator sensitive to increasing proficiency over time. The literature describing observed developmental trajectories of the constituent key skill elements of the total communication indicator provides theoretical and empirical bases for establishing their utility for earlier identification of language delays among infants and toddlers and informing sensitive ages for targeted intervention. The present study applied latent growth curve modeling (LGCM) in order to examine predictive relations within and between ECI key skill elements’ proficiencies and growth, extending previous research limited to the study of early expressive communication development measured by the total communication indicator. Findings support the hypothesis that dynamic relations exist within and between ECI proficiencies and key skill elements’ growth trajectories that may inform benchmarks and decision making related to early intervention in the development of symbolic communication and language. Future directions are discussed.

Dynamic Relations Within and Between Early Communication Proficiencies and Key Skill  
Elements' Growth Trajectories of Infants and Toddlers

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## Dynamic Relations Within and Between Early Communication Proficiencies and Key Skill Elements' Growth Trajectories of Infants and Toddlers

### Introduction

Infants and toddlers operate within physical, social, and conceptual domains through symbolic communication and language (Harwood, Giles, & Ryan, 1995). Preliteracy experiences inform language learning outcomes in early childhood, of which proficiency in expressive communication is requisite to children's cognitive and social development; language acquisition predicts significant variance in early elementary literacy achievement and school adjustment as well as long-term academic outcomes (Snow, Burns, & Griffin, 1999; Whitehurst & Lonigan, 1998). Delays in expressive communication often are not identified until preschool because of the reliance on assessment of spoken language only (Wetherby & Prizant, 1993). Such delays are among the most prevalent reasons for referring school-aged children for special education services (Marcovitch, Chiasson, Ushycky, Goldberg, & MacGregor, 1996). At least 70% of preschool children with disabilities have communication impairments (Woods & Wetherby, 2003). It is vital that identification of communication and language delays be made as early as possible to inform appropriate intervention services targeting prevention of childhood disabilities.

Recent developments in measurement align early education objectives with K-12 progress monitoring and general outcome measurement. The Early Communication Indicator (ECI; Greenwood, Carta, Walker, Hughes, & Weathers, 2006) is one of a growing class of general outcome measures emerging in early education and early childhood special education designed to identify students not making expected progress, plan changes in the intensity of early intervention, and monitor individual student progress given a change in intervention.

Comparable to K-12 curriculum-based measures, the ECI is a resource for accountability as well as response to intervention (RTI) efforts.

ECI development was informed by a national survey of parents of children with disabilities, as well as professionals in early childhood and early childhood special education, indicating a number of socially valid and desired general outcomes for young children—among which the most highly regarded outcome toward which to evaluate and monitor individual progress was the following early expressive communication outcome: “Child uses gestures, sounds, words, and word combinations to express meaning to others” (Priest et al., 2001). The ECI is designed to monitor individual progress through brief repeated measurement of early communication indicators toward this socially validated outcome.

ECI validation studies have demonstrated sound psychometric properties and technical adequacy (e.g., Greenwood et al., 2006; Luze et al., 2001). Reported indices of reliability of the ECI include inter-observer agreement of key skill elements (70-81% and 82-94% in original and Beacons study samples, respectively; Greenwood et al., 2006) and test-retest reliability of level of proficiency (i.e., intercept) based on odd versus even measurement occasions ( $r = .89$ ; Luze et al., 2001). Concurrent, criterion validity of a weighted, aggregate ECI index with the Preschool Language Scale—Third Edition (PLS-3) and a researcher developed parent-reported checklist of children’s communication proficiency has been reported as  $r = .62$  and  $r = .56$ , respectively (Luze et al., 2001). Recent longitudinal analyses evaluating predictive validity of cross-sectional time series data found that infants’ and toddlers’ early communication proficiencies predict communication outcomes four measurement occasions (i.e., one year) removed, both within and between ECI key skill elements (McConnell, 2008).

In addition to achieving high standards of technical adequacy, the ECI is exemplar of general outcome measures, demonstrating the six criteria proposed for assessment development by Deno, Mirkin, and Chaing (1982): (1) identifies authentic child behaviors in natural settings; (2) assesses key skill elements representative of an important child outcome; (3) is standardized and replicable to ensure comparability of discrete measurements; (4) demonstrates sound psychometric principles required to provide accurate information for interpretation and use for intervention decision making; (5) is sensitive to growth over time for facility in evaluating intervention effectiveness; and (6) is efficient and economical, resulting in maximum accessibility.

Feasibility of the ECI as an early education equivalent to K-12 curriculum-based measures was first demonstrated by Luze et al. (2001) in a study of two potential general outcome measures for assessing growth in expressive communication among children from birth to age three. Findings indicated that ECI key skill elements reliably changed with age, demonstrating both positive and negative growth. As a result, differential scaling (Isaac & Michael, 1978, as cited in Luze et al., 2001) was used to inform a total communication indicator sensitive to increasing proficiency. Current practice dictates the use of the total communication indicator for continuous progress monitoring and intervention decision making, despite the following.

A number of studies has evidenced sensitivity of the ECI to growth over time as well as to individual differences, namely disability status and receipt of IDEA Part C early intervention services. The observed rates of key skill elements vary predictably by age, and significant differences in expressive communication growth and proficiency indicate generally slower language development and later onset of linguistic skills among infants and toddlers having



identified disabilities (Greenwood et al., 2006; Greenwood, Walker, & Buzhardt, 2010; Luze et al., 2001). Single-subject research has demonstrated sensitivity of the measure to short-term exposures to early intervention (Greenwood, Dunn, Ward, & Luze, 2003; Kirk, 2006; Murray, 2002).

Results of previous research evaluating the ECI are consistent with widely accepted theories of language suggesting that simpler elements of communication precede more complex language development (Santrock, 2001; Greenwood et al., 2006; Luze et al., 2001). Distinct patterns of growth and stability emerge for each of the four key skill elements comprising the expressive communication outcome toward which the ECI was developed to monitor: gestures, vocalizations, single-word utterances, and multiple-word utterances (see Figure 1). The period between six and 12 months of age is characterized by prelinguistic communication (i.e., gestures and vocalizations). Meaningful growth in the frequency of observations of single-word utterances begins between 12 and 15 months; growth in multiple-word utterances begins between 18 and 21 months. Infants' and toddlers' usage of gestures and vocalizations declines with their acquisition of spoken language.

Findings inform the hypothesis that dynamic relations exist within and between ECI key skill elements' proficiencies and growth trajectories that may inform benchmarks and decision making related to early intervention in the development of symbolic communication and language. Consideration of the parallel developmental profiles of gestures, vocalizations, single-word utterances, and multiple-word utterances may suggest periods of heightened sensitivity to targeted intervention, adding considerable value to previous research limited to the examination of the total communication indicator.

The overarching objective of the present study is to improve existing knowledge of the precursors of language and literacy—the continuum of skills from infancy into preschool, advancing early education general outcome measurement, specifically the Early Communication Indicator. Evaluating dynamic relations within and between ECI key skill elements' growth parameters extends recent developments in measurement promoting alignment of early education and early childhood special education with K-12 education objectives and practices toward earlier identification of language delays prior to preschool enrollment.

## Methods

### *Sample*

Participants were infants and toddlers recruited from Early Head Start (EHS) programs representing urban, suburban, and rural localities across Kansas and Missouri. Of 5,111 infants and toddlers, 2,299 enrolled in 13 Kansas EHS programs ( $n = 1,430$ ; 62.20%) and 13 Missouri EHS programs ( $n = 869$ ; 37.80%) met the inclusion criterion; children having three or more repeated Early Communication Indicator (ECI) observations were included<sup>1</sup>. English was the primary language spoken in the home for 89.82% ( $n = 2,056$ ) of participants; 52.54% ( $n = 1,208$ ) of participants were male; 9.13% ( $n = 210$ ) of participants were eligible to receive IDEA Part C early intervention services (indicated by an Individual Family Service Plan [IFSP]).

### *Measure*

The Early Communication Indicator (ECI) is a general outcome measure developed for use with infants and toddlers aged 6 to 42 months. The ECI was adopted as an accountability measure by Early Head Start (EHS) in 2002. Infants and toddlers participating in EHS programs across Kansas and Missouri were screened quarterly using the ECI, which quantifies the occurrence of four key skill elements—gestures, vocalizations, single-word utterances, and

multiple-word utterances—in the context of formal observations of children’s communicative proficiency during 6-minute play sessions with a familiar adult partner and standard toy set.

*Gestures* are defined as physical movements made by the child in an attempt to communicate with the partner. *Vocalizations* are non-word verbal utterances voiced by the child to the play partner, occurring alone or with gestures. *Single-word utterances* are either singular voiced or signed words by the child that are recognized and readily understood by the partner. *Multiple-word utterances* are two or more different voiced or signed words by the child that are readily understood by the partner.

The frequencies of occurrence of the four ECI key skill elements were recorded and converted into rates per minute. The total communication indicator or composite rate can be calculated by summing the weighted frequencies of the four key skill elements—single and multiple word utterances are weighted by factors of 2 and 3, respectively—and dividing by total administration time.

ECI assessors (i.e., program advocates, trained home visitors, and care staff) were calibrated to administer the measure using manuals, workshop experiences, practice assessments, assessment coding, and standards for inter-observer agreement (See <http://www.igdi.ku.edu> to access calibration materials). Data were entered by assessors into a security protected website and populated a central Oracle database.

### ***Analyses***

The present study applied latent growth curve modeling (LGCM) in order to evaluate predictive relations within and between early expressive communication indicator proficiencies and growth. Four univariate latent trajectory models representing each of the ECI key skill elements and a combined multivariate growth model, all accommodating individually varying

times of observation, were estimated. Disability status—determined according to infants’ and toddlers’ eligibility for IDEA Part C early intervention services via an Individual Family Service Plan (IFSP)—was included as a predictor of latent slope and intercept factors in all proposed models. Substantive analyses were completed using Mplus Version 6.1.

*Missing Data Estimation.* Complete ECI assessment data (i.e., 11 quarterly measurements between six months and three years of age) were available for 19 (0.83%) infants and toddlers. The mean number of repeated observations among the sample was 4.82 ( $SD = 1.91$ ). Enrollment at varying ages and changing eligibility inform missingness. Additionally, provided the adoption of the ECI by community-based EHS programs servicing low-income families, significant attrition due to relocation is expected. For these and other reasons—as in most developmental and longitudinal studies—ECI research is particularly vulnerable to missing data.

Managing missing data in regard to either individuals or contexts allows one to recover key information (Schafer & Graham, 2002). Ad hoc missing data procedures such as listwise and pairwise deletion, mean substitution, regression predictions, and other forms of single imputation have been conclusively shown to perform poorly except under very restrictive or special conditions (Little & Rubin, 1987). Unlike these methods, modern missing data procedures are based on sound theory and can produce efficient estimates and accurate measures of statistical uncertainty (Collins, Schafer, & Kam, 2001).

Accordingly, full information maximum likelihood (FIML) was chosen to handle incomplete assessment data in the sample. In contrast to approaches in which missing data and substantive model estimation are performed separately, FIML model parameters were estimated from incomplete data in a single step without preliminary or additional calculations or iterations (Little, Bovaird, & Card, 2007).

In addition to incomplete assessment data, infants' and toddlers' ECI observations were unbalanced on time, yielding few replications at any time point and an excessively large number of missing data patterns. The proposed latent trajectory models are aptly suited to accommodate alternative metrics of time for unbalanced data, an advantage of LGCM over other analytic approaches including repeated measures ANOVA (Singer & Willett, 2003).

*Alternative Metrics of Time.* Latent growth curve models allow the user to specify the number of indicators defining the growth factors equal to the number of discrete time-specific measures available in the data. As the number of time-specific measures rises, the definition and estimation of the model becomes increasingly complex. The current sample contained 1,359 unique time-specific measures of expressive communication, including many observed for only a single assessment.

One solution to modeling these unbalanced data is to treat observations as time-structured by selecting wave or projected age at observation (i.e., estimated age at quarterly assessments; 6, 9, 12, 15, 18, etc. months) as the temporal predictor, which has been done in all previous evaluations of the ECI. However, the use of either results in over- or underestimated fixed effects of growth because projected age, for example, associates data for subsequent waves with younger or older ages than observed. If we amortize the same gain over shorter or longer periods, slope estimates will be either exaggerated or attenuated. The use of projected age also produces larger estimated variance components because the model with a time-structured predictor fits less well than when each individual's data is associated with his/her actual age at testing. In sum, treating an unbalanced dataset such as the present as time-structured introduces error into the analysis, which can be reduced by choosing the infants' and toddlers' ages at testing as the temporal predictor, providing more precise information than time-structured alternatives.

Recent developments in individual-based methods of estimation provide the second, more appropriate solution to modeling the unbalanced sample (Mehta & Neale, 2005, Mehta & West, 2000). Individual likelihood-based estimation allows the measure of time to vary freely over individuals; age is treated as a variable used to define the fixed values of the lambda matrix defining growth factors in the latent model. Infants' and toddlers' observed ages are coded into individual-specific factor loading matrices, and these matrices are then summed into the estimation of the overall likelihood function. The TSCORES option in Mplus was used to execute this solution to latent growth curve modeling (LGCM) with time-unstructured repeated observations.

*Latent Growth Curve Modeling.* LGCM provides the facility to evaluate developmental trajectories as a function of repeated observations. Of analytic interest in LGCM is not the repeated measures observed; rather, the interest is in the unobserved latent factors that inform the observed repeated measures and their interrelations. Whereas the majority of traditional analytic methods evaluate and predict change as a function of the relation between two adjacent time points using parameters that are common across cases, LGCM posits the existence of continuous underlying trajectories that differ by case and are defined indirectly by the pattern of change observed in repeated measurements (Bollen & Curran, 2006).

LGCM allows estimation of individual change as well as the average pattern of change, interindividual (i.e., between-persons) variability in intraindividual (i.e., within-person) change, and associations between growth parameters. The correlates of change inform understanding of the influences of development. Latent trajectory models also enable predictors of individual differences yielding effects of endogenous influences on rates of development.

Latent factors represent chronometry common factors indicating individual differences over time and can be parameterized to allow for the estimation of specific functional forms of growth. The mean developmental trajectories of ECI key skill elements include both positive and negative growth. Given that variable rates and direction of change in particular key skill elements across time may inform periods of heightened sensitivity to targeted intervention, an alternative parameterization of LGCM was indicated: piecewise spline modeling.

*Piecewise Spline Modeling.* Piecewise trajectory models approximate the non functional forms that characterize prelinguistic ECI key skill elements' development via estimation of latent growth factors before and after a discontinuity in the direction of change. Informed by theories of language (Santrock, 2001), previous research (Greenwood et al., 2006; McConnell, 2008), and empirical evaluation of observed data profiles, fixed transition points representing inflections in plotted trajectories were identified for gestures and vocalizations. Parameterization of the ECI key skill elements' univariate latent growth curve models follows.

*Univariate Latent Growth Curve Models.* Existing knowledge informs the analysis of discontinuous growth in prelinguistic skills. The observed rate of gestures increases between 6 and 15 months and decreases between 15 and 24 months, before the frequency of observations demonstrates relative stability. Growth in vocalizations increases between 6 and 18 months and decreases between 18 and 36 months. Piecewise spline models representing the underlying latent trajectories of gestures and vocalizations each estimated two slope parameters corresponding to these positive and negative changes around a single intercept at the elements' respective points of inflection (i.e., 15 and 18 months). Evidence of continuous growth in spoken language supports the measurement of single-word and multiple-word utterances' latent trajectories beginning at 12 and 18 months, respectively, and having intercepts at 36 months.

Individual-specific factor loading matrices defining the latent slopes contained infants' and toddlers' observed ages in months—defined as the number of days old at the measurement occasion divided by 365, the quantity multiplied by 12—centered around the locations of latent intercepts, yielding proficiencies equivalent to model-implied mean rates of key skill elements at their greatest values.

For each of the four univariate latent growth curve models specified, parameters including latent factors' means, variances and residual variances, and covariances as well as regression coefficients for the effects of disability status on slopes and intercept were estimated freely. These estimates were used as starting values to facilitate convergence and inform optimal maximum likelihood (ML) solutions in the multivariate latent growth model described below.

*Multivariate Latent Growth Curve Model.* In addition to establishing the underlying latent profile of ECI key skill elements' development using univariate methods, multivariate latent growth curve modeling was endeavored to estimate dynamic relations between expressive communication elements' latent growth factors toward demonstrating the utility of ECI key skills in earlier identification of language delays. Regression coefficients for effects of simpler communication elements' latent factors on subsequent slope and intercept factors of more complex communication skills are hypothesized to provide meaningful indicators of need for targeted intervention. For example, infants and toddlers not demonstrating expected decreasing rates of observations of prelinguistic skills following the average age of spoken language acquisition may require services intended to facilitate replacement of ancillary expression in order to moderate negative prediction of 36-month communication outcomes.

As in the univariate growth models, individual-specific factor loading matrices of infants' and toddlers' observed ages at the time of measurement (centered around key skill elements'



latent intercepts) defined multivariate slope factors. Covariances between latent factors not hypothesized to predict later slope and intercept parameters were freely estimated. Disability status (IFSP) was included as a predictor of all latent factors in the multivariate model.

## Results

### *Univariate Latent Growth Curve Models*

The four univariate latent model-implied mean trajectories were consistent with previously reported developmental profiles of gestures, vocalizations, single-word utterances, and multiple-word utterances. Reliably significant intercept and slope variances across models indicate that infants and toddlers differed in their highest proficiencies and rates of growth in ECI key skill elements, supporting the plausibility of predictive relations between growth factors that may inform benchmarks and decision making related to early intervention. Results extended prior findings of sensitivity of the total communication indicator to individual characteristics to each of the four key skills. Eligibility for IDEA Part C early intervention services via an IFSP predicted significant differences in expressive communication proficiencies and development. The observed persistence of positive growth (i.e., developmental continuity) in prelinguistic elements among infants and toddlers having identified disabilities—provided by piecewise spline model results—suggests the dynamic relation between simpler elements of communication and more complex language development. Failure to demonstrate negative growth in gestures and vocalizations near the expected ages of acquisition of spoken language elements may predict insufficient development of more complex language indicators and inform periods of heightened sensitivity to targeted intervention.

*Gestures.* The mean rate per minute of gestures at 15 months was 1.694 ( $SD = 0.032$ ). Growth increased at an average rate of 0.069 ( $SD = 0.005$ ) gestures per minute between quarterly

measurement occasions between the ages of 6 and 15 months and declined thereafter at an average rate of  $-0.026$  ( $SD = 0.005$ ) between quarterly measurements to 24 months before stabilizing. IFSP predicted change in gestures such that infants and toddlers having identified disabilities demonstrated slightly positive growth between 15 and 24 months ( $M = 0.016$ ;  $SD = 0.018$ ). See Figure 2.

*Vocalizations.* The greatest mean rate per minute of vocalizations was 3.700 ( $SD = 0.052$ ) and occurred at the 18-month intercept. Infants and toddlers demonstrated positive growth at an average rate per minute of 0.184 ( $SD = 0.007$ ) vocalizations between quarterly measurements from 6 to 18 months and negative growth at an average rate per minute of  $-0.126$  ( $SD = 0.004$ ) between quarterly measurements from 18 to 36 months. Consistent with piecewise spline model findings related to prelinguistic gestures, infants and toddlers having identified disabilities demonstrated slightly positive growth in vocalizations between 18 and 36 months ( $M = 0.041$ ;  $SD = 0.015$ ). See Figure 3.

*Single-word Utterances.* The outcome mean rate of single-word utterances at 36 months was 3.806 ( $SD = 0.056$ ) per minute. The frequency of observations of single-word utterances increased continuously between quarterly assessments from 12 to 36 months at an average rate per minute of 0.155 ( $SD = 0.002$ ). IFSP predicted significantly fewer single-word utterances at 36 months ( $M = 2.791$ ;  $SD = 0.161$ ) and lesser positive growth ( $M = 0.114$ ;  $SD = 0.007$ ) among infants and toddlers having disabilities relative to typically developing peers. See Figure 4.

*Multiple-word Utterances.* The mean rate per minute of multiple-word utterances at 36 months was 4.303 ( $SD = 0.089$ ). Growth in multiple-words increased continuously at an average rate of 0.235 ( $SD = 0.005$ ) utterances per minute between quarterly measurements from 18 to 36 months. IFSP predicted 36-month multiple-word utterances mean rate as well as growth between

18 and 36 months. Comparable to findings related to single-word utterances, infants and toddlers requiring IDEA Part C early intervention services used significantly fewer multiple-word utterances at 36 months ( $M = 2.007$ ;  $SD = 0.183$ ) and demonstrated significantly lesser positive growth than typically developing peers ( $M = 0.105$ ;  $SD = 0.011$ ). See Figure 5.

### ***Multivariate Latent Growth Curve Model***

The proposed combined multivariate latent growth curve model including all four ECI key skill elements' trajectories could not be estimated despite regards to the estimator, variable scaling, maximum iterations, and start values (see Appendix A). A number of predictive relations was found between latent factors of bivariate growth curve models representing the continuum of early expressive communication skill development: gestures to vocalizations, vocalizations to single-word utterances, and single-word to multiple-word utterances. Results were consistent with existing theory maintaining that simpler elements of communication precede more complex language development.

*Gestures and Vocalizations.* The underlying latent trajectory of growth in gestures between 6 and 15 months significantly and positively predicted the mean rate per minute of vocalizations at 18 months. A one-unit increase in the average growth in gestures between quarterly measurements projected a 3.386 ( $SD = 1.667$ ;  $p = .042$ ) per minute increase in the subsequent rate of vocalizations. Infants and toddlers demonstrating faster growth in prelinguistic gestures before 15 months achieved greater vocalization rates at 18 months on average.

*Vocalizations and Single-word Utterances.* The mean rate per minute of vocalizations at 18 months significantly and positively predicted the mean rate of single-word utterances per minute at 36 months ( $\beta = 0.080$ ;  $SD = 0.029$ ;  $p = .005$ ). The infants and toddlers expressing

greater rates of vocalizations at the inflection in the discontinuous mean trajectory of the prelinguistic indicator achieved greater subsequent rates of single-word utterances.

The average negative growth in vocalizations following the inflection or between 18 and 36 months also predicted subsequent rates of single-word utterances such that infants and toddlers not demonstrating declining (i.e., negative) growth in vocalizations communicated fewer single-word utterances at 36 months. A one-unit increase in the average rate of growth in vocalizations between quarters informed a  $-3.267$  ( $SD = 1.078$ ;  $p = .002$ ) utterance per minute change in the mean rate of single words.

*Single-word Utterances and Multiple-word Utterances.* The average underlying trajectory of growth in single-word utterances from 12 to 36 months significantly predicted the mean rate of multiple-word utterances per minute at 36 months. A one-unit increase in average growth in single-words between quarterly assessments projected a  $24.585$  ( $SD = 2.781$ ;  $p = .000$ ) utterance per minute increase in the rate of subsequent multiple-word utterances. Infants and toddlers demonstrating accelerated growth in the acquisition of single-word utterances achieved greater 36-month multiple-word communication rates.

## Discussion

Conceptualizing communication proficiencies and growth as latent developmental trajectories allowed both articulation and assessment of research questions not accommodated by other approaches. The present study utilized LGCM to achieve its objectives of estimating the underlying trajectories and projecting the utility of the ECI key skill elements for early identification of language delays. Findings improve existing knowledge of the precursors of language and literacy and promote early education general outcome measurement by sustaining

support to educators, caregivers, and interventionists in the case for continuous progress monitoring and targeted intervention in early education and early childhood special education.

The univariate models established the plausibility and suggested the need to evaluate predictive relations between latent factors to explain significant variances in ECI key skill elements' development beyond that for which modeled individual differences accounted. The results extend prior information that infants and toddlers having identified disabilities demonstrate later onset of linguistic skills and generally slower language development by providing that, on average, they also present with continued growth in gestures and vocalizations after the expected ages defining discontinuity and characterized by decreasing rates of these. This observation may explicate an important function between simpler and more complex communication elements. Failure to demonstrate expected growth in prelinguistic indicators may predict spoken language delays. The bivariate analyses supported this hypothesis.

Results of models including predictive relations between growth factors of pairs of indicators representing the continuum of early expressive communication development validate the utility and justify use of the ECI key skill elements for continuous progress monitoring and intervention decision making. For example, infants' and toddlers' observed growth in gestures between 6 and 15 months could be monitored against the underlying trajectory to inform risk for suboptimal achievement of vocalizations rate at 18 months, which subsequently predicts expression of single-word utterances at age three. The bivariate models also suggest periods of sensitivity to targeted intervention toward preventing spoken language delays. For example, evaluation of infants' and toddlers' trajectories of vocalizations can be used to identify divergence from negative growth expected after 18 months and indicate the need for services

intended to facilitate replacement of ancillary expression with single- and multiple-word utterances.

### ***Strengths and Limitations***

The reported analyses feature strengths and add significant value to the line of research evaluating the ECI for general outcome measurement. The advantages of latent trajectory models over alternatives for studying longitudinal data are many. Their suitability to accommodating unbalanced, time-unstructured repeated measures and approximating non functions through piecewise parameterization is particularly relevant.

The inclusion of individual-specific matrices of time indicating infants' and toddlers' actual ages at assessment represents improvement to existing ECI models toward unbiased estimates of growth and variance. The parameterization of growth before and after discontinuity in the direction of change in prelinguistic indicators provided new information for benchmark decision making based on ECI key skill elements.

The large sample of data analyzed supports the generalizability of findings of early expressive communication development to infants and toddlers enrolled in EHS. Notably, the EHS population is characterized by disadvantaged socioeconomic status; therefore, the underlying latent trajectories and interrelations established in the current study may not apply to early expressive communication development of infants and toddlers generally. The widespread adoption of ECI progress monitoring in early childhood education requires additional research.

The current study is also limited to predictions between bivariate growth factors. The model including all four ECI key skill elements could not be estimated as a result of nonconvergence due to unbalanced and/or insufficient data and complexity. The combined multivariate latent growth curve model may be estimable fit to alternative samples.

### ***Future Directions***

An important prospective objective of research evaluating the ECI is identification of potential subpopulations—possibly including infants and toddlers having identified disabilities—to which membership is inferred by distinct, developmental trajectories of early expressive communication skills. Accordingly, multilevel mixture modeling should be considered a logical next step for improving existing knowledge of the precursors of language and literacy and for continued advancement of early education general outcome measurement toward increasingly effective targeted intervention services.

Additionally, the present findings suggest that continuous progress monitoring of growth in gestures, vocalizations, single-word utterances, and multiple-word utterances may be used to project infants' and toddlers' likelihood of success in achieving proficiency in increasingly complex expressive communication skills. Future research evaluating the ECI should inform key skill elements' benchmarks toward predicting subsequent language outcomes through categorical approaches.

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## Footnotes

<sup>1</sup> The inclusion criterion for the analyzed sample is three or more repeated ECI observations, and is informed by the complexity of the proposed statistical models. Longitudinal modeling dictates that individuals having fewer than three repeated measurements provide minimal or no information regarding within-person variation, and hence do not contribute to variance component estimation, while simultaneously exhausting significant computational resources. The importance of observing enough children having sufficient waves of data for the numerical algorithms to converge cannot be understated. In the present case, this consideration limits the sample of infants and toddlers to 2,299 (44.98% of available data).

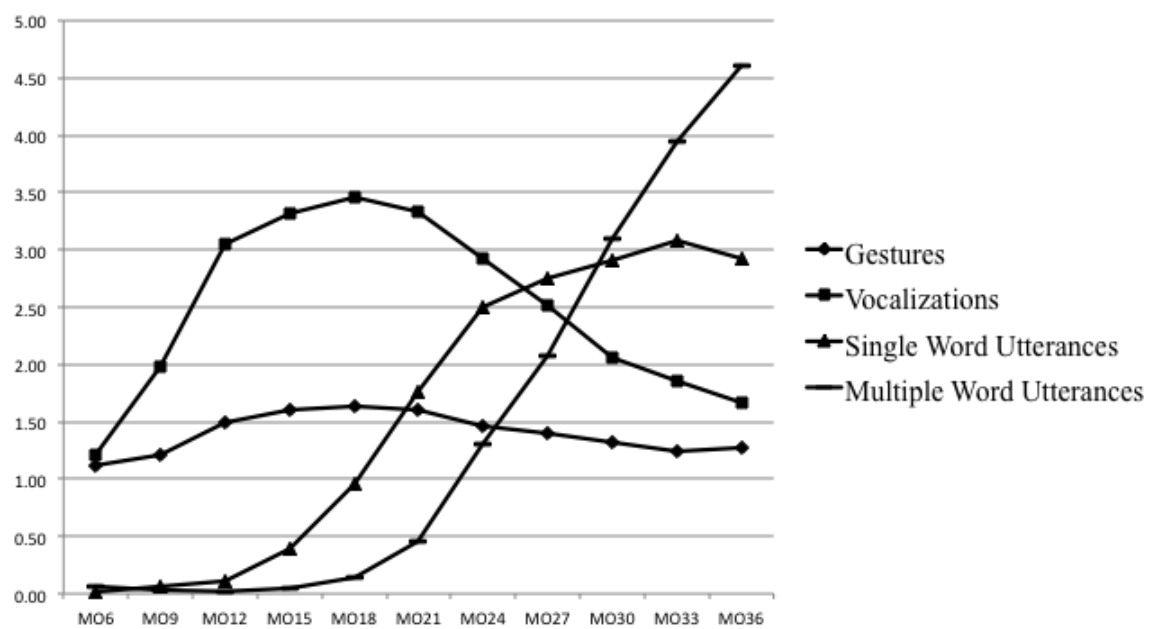


Figure 1. Mean observed trajectories of ECI key skill elements' rates per minute.

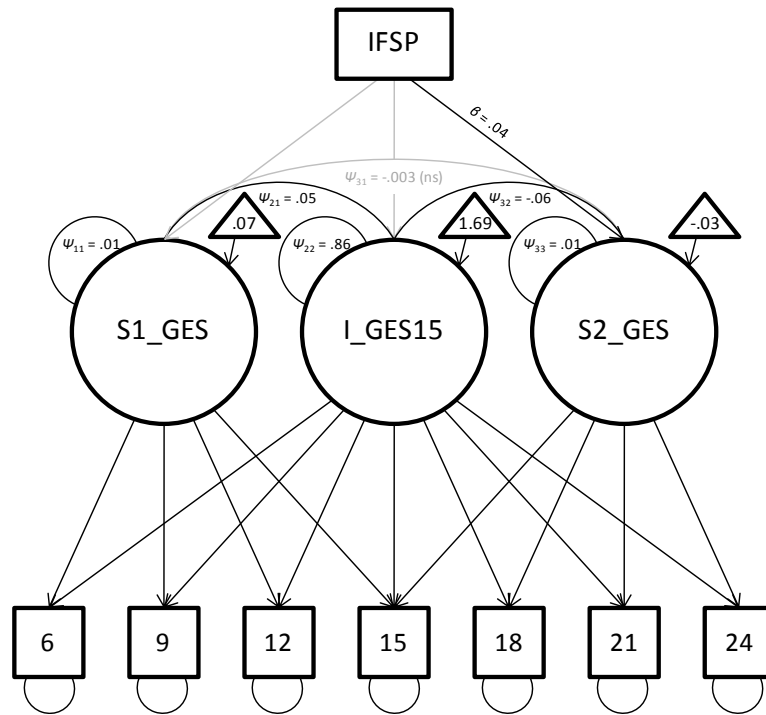


Figure 2. Univariate piecewise spline model for gestures.

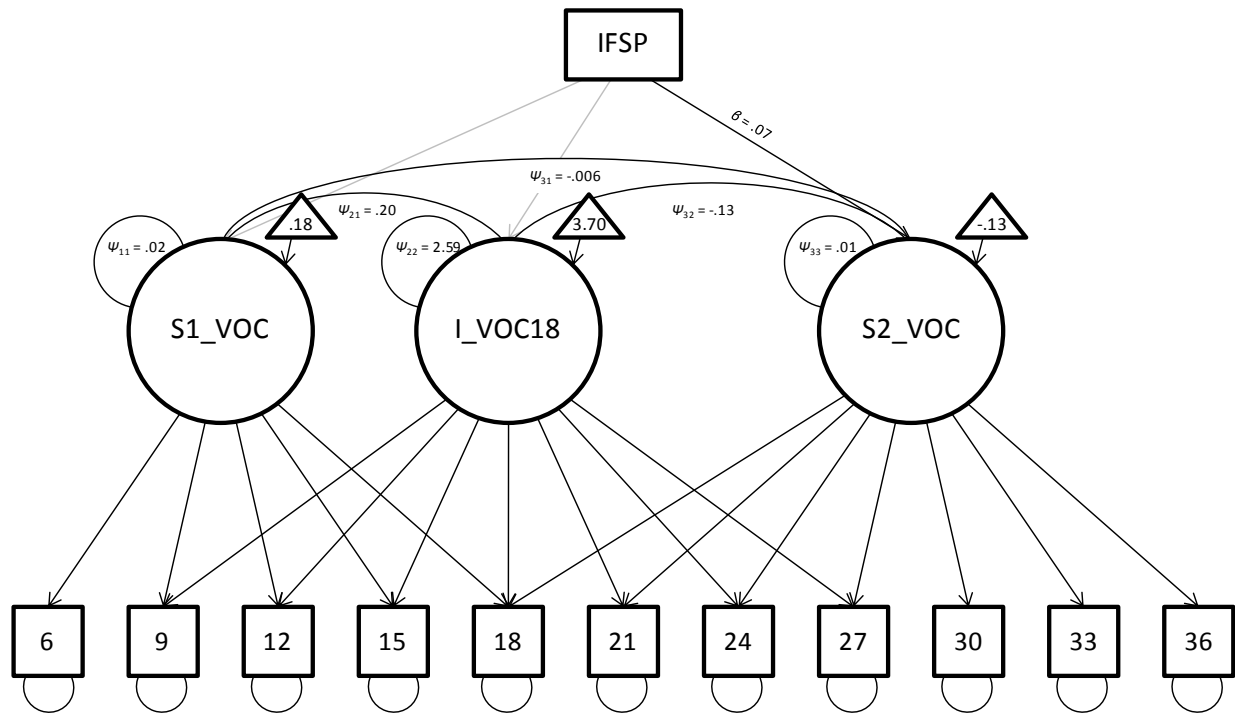


Figure 3. Univariate piecewise spline model for vocalizations.

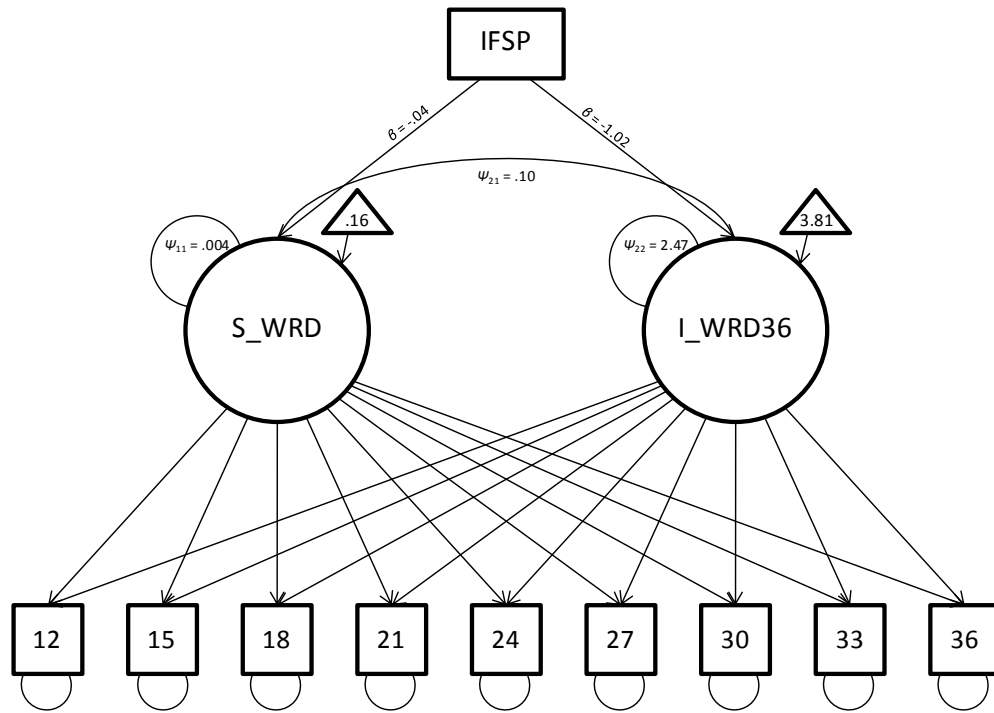


Figure 4. Univariate latent growth curve model for single-word utterances.

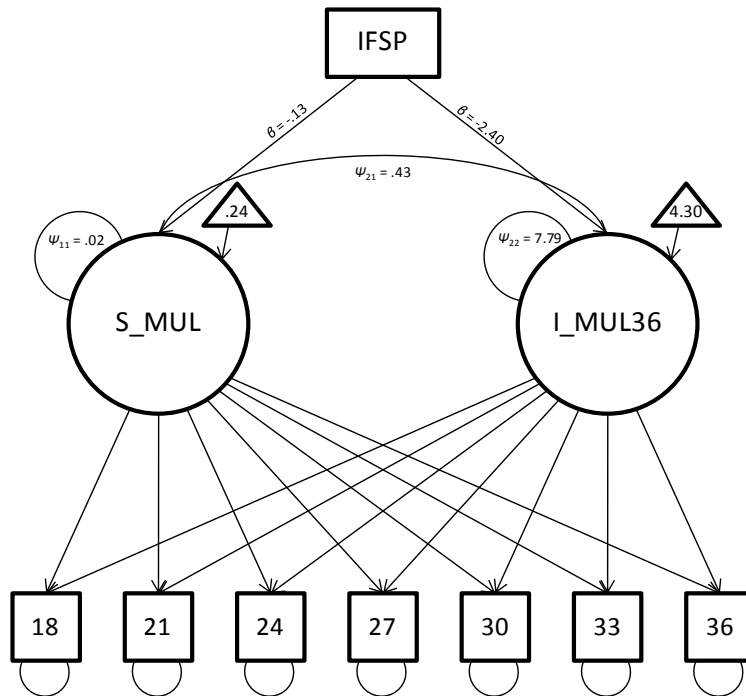


Figure 5. Univariate latent growth curve model for multiple-word utterances.



## Appendix A

### Nonconvergence

The number of iterations required for model convergence increases as a product of unbalanced data and model complexity, both of which characterize the proposed multivariate latent growth curve model of the four ECI key skill elements. According to Singer & Willett (2003), any given dataset contains a finite amount of information; “[a researcher] can postulate a complex model, but it is not always possible to fit that model to the available data.” In addition, certain models and data properties are more likely than others to preclude parameter estimation. The choice of estimator, variable scaling, maximum iterations, and start values can also inform success in facilitating convergence.

*Maximum Likelihood Estimation.* The classic derivation of maximum likelihood estimation (MLE) assumed multivariate normality; however, situations in which MLE is appropriate can include modeling of observed variables derived from a nonnormal distribution. Examination of the distributions underlying ECI key skill elements’ rates per minute indicate moderately positive skew. According to Mîndrilă (2010), MLE produces relatively accurate parameter estimates given nonnormal continuous data such as the present; however, standard errors are underestimated, which may inform nonconvergence due to insufficient variances in random effects factors that are required for estimation of growth parameters when defined by individually varying times of observation. The value added to ECI research by utilizing individual likelihood-based estimation of time through the TSCORES option in *Mplus* precludes re-specification to a fixed effects model—one possible solution to nonconvergence due to small variances in random effects resulting from the improper choice of estimator. An alternative solution to nonconvergence involved transforming key skill elements’ rates in order to meet

normality assumptions of MLE. Based on the observed distributions of the four analyzed expressive communication indicators, new variables were defined prior to model estimation by calculating the square root of original values. The model did not converge.

*Variable Scaling.* The values of a variable inform the variance components optimized in the iterative process of model estimation. The values of ECI key skill elements' mean rates per minute are small (ranging from 0.106 to 4.560) and therefore provide yet smaller variance components. Nonconvergence may result from issues related to errors in rounding of very small values such as these. Singer & Willett (2003) suggest simple multiplication of the outcome to address this potential challenge in estimation. Accordingly, observed rates of gestures, vocalizations, single-words, and multiple-word utterances were increased by factors of ten and 100 to facilitate computation of variance components and parameter estimation. The model with rescaled variables reached maximum iterations without convergence.

*Maximum Iterations.* There are two presentations of nonconvergence in statistical modeling (Muthén & Muthén, 2010). First, software stops before convergence because the maximum number of iterations was reached, the response to which involves sequentially increasing the maximum number of iterations allowed from the default (i.e., 500 in Mplus). Convergence of the proposed model could not be achieved after 10,000 EM iterations. Second, maximum iterations are reached due to difficulties in optimizing the fitting function for the specified model, which can result from misspecification and/or insufficient data. Another challenge to optimizing the fitting function is the start values used in the initial stage iteration.

*Start Values.* In addition to requesting 500 and fewer sets of automatic randomly perturbed initial stage iteration start values for all parameters in the model except variances and covariances, parameter values estimated for univariate latent growth curve models of ECI key

skill elements were provided to facilitate convergence; none of these succeeded to provide parameter estimates for the proposed multivariate model.